Data Analysis, Modeling, and Ensemble Forecasting to Support NOWCAST and Forecast Activities at the Fallon Naval Air Station

Darko Koracin
Desert Research Institute
2215 Raggio Parkway, Reno, NV 89512
phone: (775) 674-7091 fax: (775) 674-7060 email: Darko.Koracin@dri.edu

John Lewis
Desert Research Institute
2215 Raggio Parkway, Reno, NV 89512
phone: (775) 674-7077 fax: (775) 674-7060 email: John.Lewis@dri.edu

Award Number: N00014-08-1-0451
http://www.dri.edu

LONG-TERM GOALS

The goals of this project are to increase our understanding of weather predictability and to develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.

OBJECTIVES

The main objectives of the study are: 1) To further develop and test a real time Mesoscale Model 5 (MM5) forecasting system with sub-kilometer horizontal resolution to support the NOWCAST system at the Fallon Naval Air Station (NAS); 2) To provide a basis for a multi-model ensemble forecasting by developing an operational version of an additional mesocale model: the Weather and Research Forecasting model (WRF); 3) To include at a later stage the Coastal Oceanic and Atmospheric Modeling Prediction System (COAMPS) into a multi-model ensemble; and 4) To develop methods of mesoscale multi-model ensemble forecasting to improve the applicability of the forecasts and nowcasts.

APPROACH

We have developed a fully self-sustained forecasting system, consisting of two regional-mesoscale models MM5 and WRF, to support NAS Fallon operations. The system results are posted on a dedicated web site with password protection [URL: http://www.adim.dri.edu/] and are updated with model runs every 12 hrs [Fig. 1]. The system has been tested and is now in operation on a multi-processor computer Cray XD1 located in the Division of Atmospheric Sciences at the Desert Research Institute (DRI).

As a background for the near-future development of ensemble forecasting techniques, a coarse domain with a resolution of 108 km was added to the real time system. This domain is being currently operationally run for 15 days (360 hrs) forecast time. The next domain with a resolution of 36 km has

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Data Analysis, Modeling, And Ensemble Forecasting To Support NOWCAST And Forecast Activities At The Fallon Naval Air Station**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Desert Research Institute,2215 Raggio Parkway,Reno,NV,89512**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The goals of this project are to increase our understanding of weather predictability and to develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**10**	

also an extended forecast time of 7.5 days (180 hrs). The length of the forecasts was dictated by the computational resources. These simulations will allow sufficient statistics for analysis of the model accuracy with respect to the lead time.

Fig. 1. The main web page of DRI's real time MM5 and WRF forecasting systems [http://www.adim.dri.edu/]. Web links to various components of the system are shown in separate panels (upper middle and going clockwise): Forecast charts and animations, Other useful links, Ensemble forecasting (in construction), Forecast of transport and dispersion of dust and pollutants, Model verification, and GIS Imagery of the models domains.

One of the primary goals of this study is to develop useful techniques and methodologies for regional-mesoscale multi-model (COAMPS, WRF, and MM5) ensemble forecasting (Lewis 2005). In this initial phase of the development of the multi-model ensemble forecasting techniques, we focused on analysis of forecasting results from both global and regional-mesoscale models. Prior to using and analyzing results from WRF, MM5, and COAMPS, it is valuable to understand the capabilities and limitations of the global models that are providing initial and boundary conditions for the regional-mesoscale models. The first step in the investigation included correlation analysis between the model forecasts and the objectively analyzed (re-analysis) field. The next step in the examination focused on the root-mean-square errors of the main meteorological parameters as a function of the forecast lead time for various parameters and heights using 39 radiosonde sites in western and central North America.

For the testing of the NAS Fallon real time forecasting system as well as the Global Forecast System (GFS) and the North America Regional Re-analysis fields (NARR), we selected case studies of intense winter storm systems associated with high winds and extensive precipitation in the Fallon area as well as in broader regions of California, Nevada, and the southwest. To provide more significant statistics of the models' performance, we also analyzed longer time forecast periods in winter and summer months.

Dr. Darko Koracin (P.I.) was responsible for the mesoscale modeling, model evaluation, and development and testing of the methodologies for the multi-model ensemble forecasting.

Dr. John Lewis (co-P.I.) was responsible for data assimilation techniques and development of the ensemble forecasting methodologies.

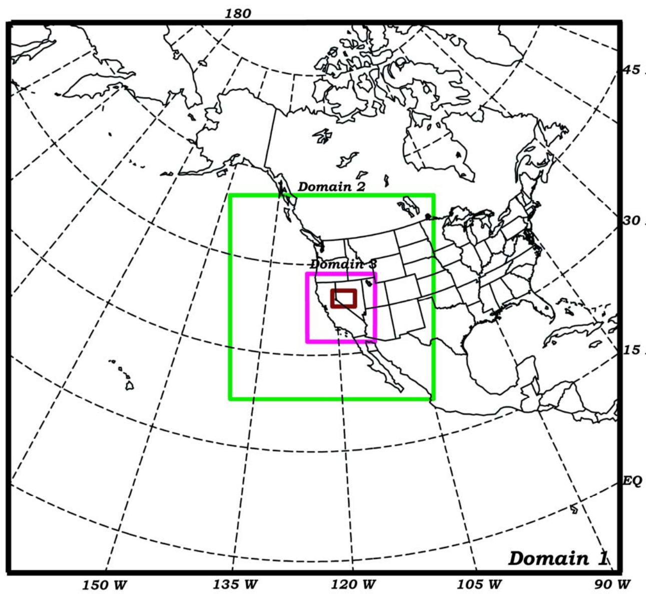
WORK COMPLETED

To support real-time forecasting and nowcasting at the Fallon Naval Air Station, surface meteorological stations were operational during the project period. The location specifications of these sites are:

- Fallon 31ESE [NAS B17] at Fairview Valley (39°19'27" N, 118°13'22" W, 4235' MSL).
- Fallon 23SSE [NAS B19] at Blowing Sand Mountains (39°08'31"N, 118°40'01"W, 3886' MSL).
- Fallon 36NE [NAS B20] at Carson Sink (38°54'40" N, 118°23'14" W, 3881' MSL).
- Fallon NAS EW71 Edwards Creek Valley (39°31'57" N, 117°44'50" W, 5192' MSL).

We have provided maintenance on these stations, including installing a sonic anemometer at the B17 station. The sonic anemometer has been in continuous operation since February 2007. The high frequency (20 Hz) flux and turbulence data from the sonic anemometers allow us to evaluate various turbulence parameterizations that are widely used in mesoscale models (MM5, COAMPS™, and WRF). This will aid in selecting optimum turbulence parameterizations that can be used for multi-model real-time forecasting in the Fallon area as well as input to a Lagrangian random particle dispersion model for predictions of dust and other chemicals in the domains (Koracin et al. 2007; Isakov et al. 2007).

The real-time MM5 and WRF system was developed and installed on an XD1 Cray computer at the Desert Research Institute. To account for synoptic processes and also to resolve the characteristics of the mesoscale processes, coarse and nested grids were set up to cover a large area with the highest resolution of 444 m centered on the NAS Fallon runway all the way to covering entire North America with the coarsest grid. There are a total of six real time WRF modeling domains, shown in Fig. 2. Domain 1 covers the entire North American region and has 103 × 93 grid points in x and y directions with grid size of 108 km. It is centered at 39.417° N and 125.000° W. As compared to the previous real time domain setup, this domain is included to capture the large scale flow in the Pacific Ocean. Domain 1 runs for a forecast period of 15 days. Domain 2 covers the U.S. West Coast, has 103 × 103 grid points in the x and y directions with a horizontal grid size of 36 km, and runs for a forecast period of 180 hours. Domain 3 is nested into domain 2, covers all of Nevada and California, employs a grid of 12 km and has the same number of grid points as in domain 2. Domains 4 (103 × 73 grid points; 4 km grid) and 5 (94 × 94 grid points; 1.333 km grid) focus on regions in central Nevada, with fine grid resolution employed in regions where the surface monitoring stations in Fallon are operational. The finest grid resolution of 444 m is in domain 6 (73 × 73 grid points; covers a region of approximately 360 square miles) which is centered at the Naval Air Station, Fallon. Domains 3 through 6 are run for a forecast period of 24 hours. The real time MM5 forecasting system has a similar configuration, but currently supports domains 2 through 6 only, and runs for 84 hours for domain 2 and for 24 hours for the inner domains. The system has been tested for weather and air quality forecasting of the western U.S. and the West Coast (Dorman and Koracin 2008; Beg Paklar et al. 2007; Weinroth et al. 2008), Mediterranean Sea (Beg Paklar et al. 2008) and transport and dispersion of dust due to rotorcraft military operations (McAlpine et al. 2007).



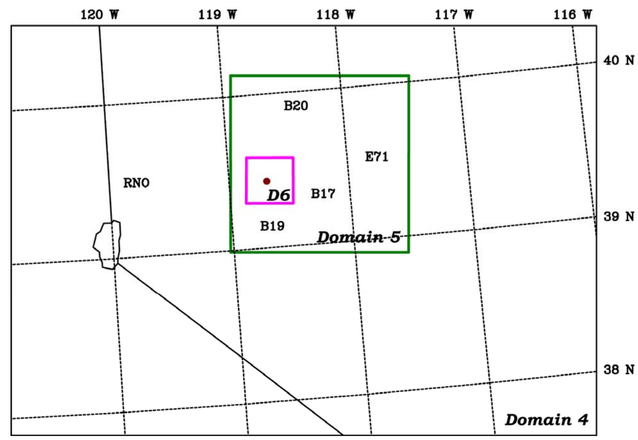


Fig. 2. Six-domain setup for the WRF and MM5 forecasting systems. Domain 1 (108 km resolution) includes all of North America and eastern and central Pacific, domain 2 (36 km resolution) encompasses the western U.S. and the eastern Pacific coastal region, domain 3 (12 km resolution) covers California and Nevada, domain 4 (4 km resolution) focuses on central and western Nevada, domain 5 (1.33 km resolution) covers the broader Fallon area including four special weather stations, and domain 6 (444 m resolution) is centered on the Naval Air Station Fallon runway.

The vertical configuration includes 36 unequally spaced layers, with 13 model levels in the lowest kilometer, and the lowest model level set at 10 m.

The initial and boundary conditions for WRF are obtained from the Global Forecasting System (GFS) 6-hourly forecasts (archived at 0.5° × 0.5° grid resolution for 180 hours) and 12-hourly forecasts (at 2.5° × 2.5° grid resolution from 180-364 hours). The Eta model forecasts (archived for a period of 84 hours on grid type 221; 32-km grid resolution; http://www.adim.dri.edu/Projects/fallon/grid221.php) archived by the Advanced Weather Interactive Processing System (AWIPS) are used in the MM5 preprocessing. Four-dimensional data assimilation (FDDA), through observation nudging, is employed to include the satellite and RADAR observations and is operational in the real time MM5 forecasting system. The WRF component of three-dimensional variational assimilation (3DVAR) is currently under experimentation. Similar model physics options are used for both MM5 and WRF with the exception that WRF uses a unified Noah land surface model to compute the surface energy budget whereas MM5 uses a multilayer soil temperature diffusion model.

The WRF and MM5 forecasting system has a new automatic pre-forecast data assimilation simultaneously using data from four meteorological stations that were set up in the NAS Fallon area during a previous ONR project (Vellore et al. 2006, 2007), WSR 84 Fallon radar data, and satellite data (a new methodology of improving model initial conditions in the vicinity of the NAS Fallon area and the initial boundary layer height over the entire model domain).

RESULTS

As the first step in preparing a methodology for multi-model ensemble forecasting, we simulated three cases of storm systems associated with severe weather and flooding in the western Nevada and eastern California. The simulations were performed using WRF for ten days using an every 12 hour forecast cycle with an 84 hour forecast length for each case. Consequently, each case consisted of 14 runs and provided 112 samples at each grid point. The model results in each grid point were correlated with the interpolated objective analysis NARR. Spatial correlation coefficients are shown in Fig. 3.

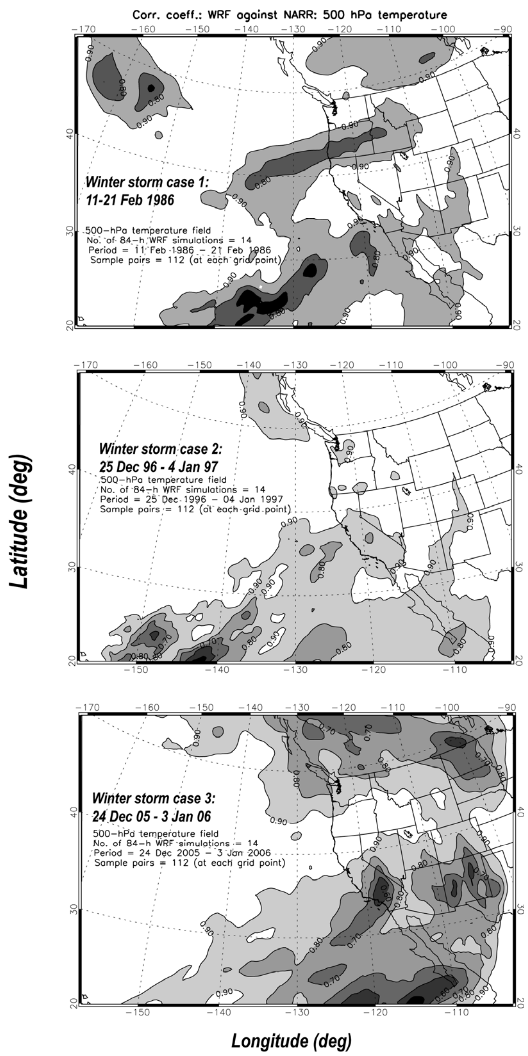


Fig. 3. Spatial distribution of the correlation coefficient for the temperature at 500 hPa between the sequential WRF 84-hr simulations for the periods: 11-21 February 1986 (upper panel); 25 December 1996 to 4 January 1997 (middle panel); and 24 December 2005 to 3 January 2006 (lower panel).

Although there are differences among these three cases distinctly separated in time, there are also similarities, especially in the southern part of the domain (subtropical belt) indicating the model's departure from the objective analysis. This brings up an interesting point of going back to the large scale model that was providing initial and boundary conditions – in this case GFS – and examining model performance. To provide a sufficient statistical sample, we used GFS forecasts for three summer and three winter months in 2008. GFS global forecasts were archived at $1° \times 1°$ grid resolution and obtained from the NOAA National Operational Model Archive & Distribution System (NOMADS; http://nomads.ncdc.noaa.gov). These forecasts from the global spherical grid were regridded to 36 km grid resolution on a Cartesian plane using Lambert Conformal Projection centered at 39.417 N and 125 W. The forecasts were evaluated using data from 39 radiosonde stations in western and central North America. The RMSE as a function of the lead time was computed with respect to data from 39 radiosondes for the twice-daily forecasts during three months in winter and three months in summer. The results for the air temperature and u and v wind components are shown in Fig. 4.

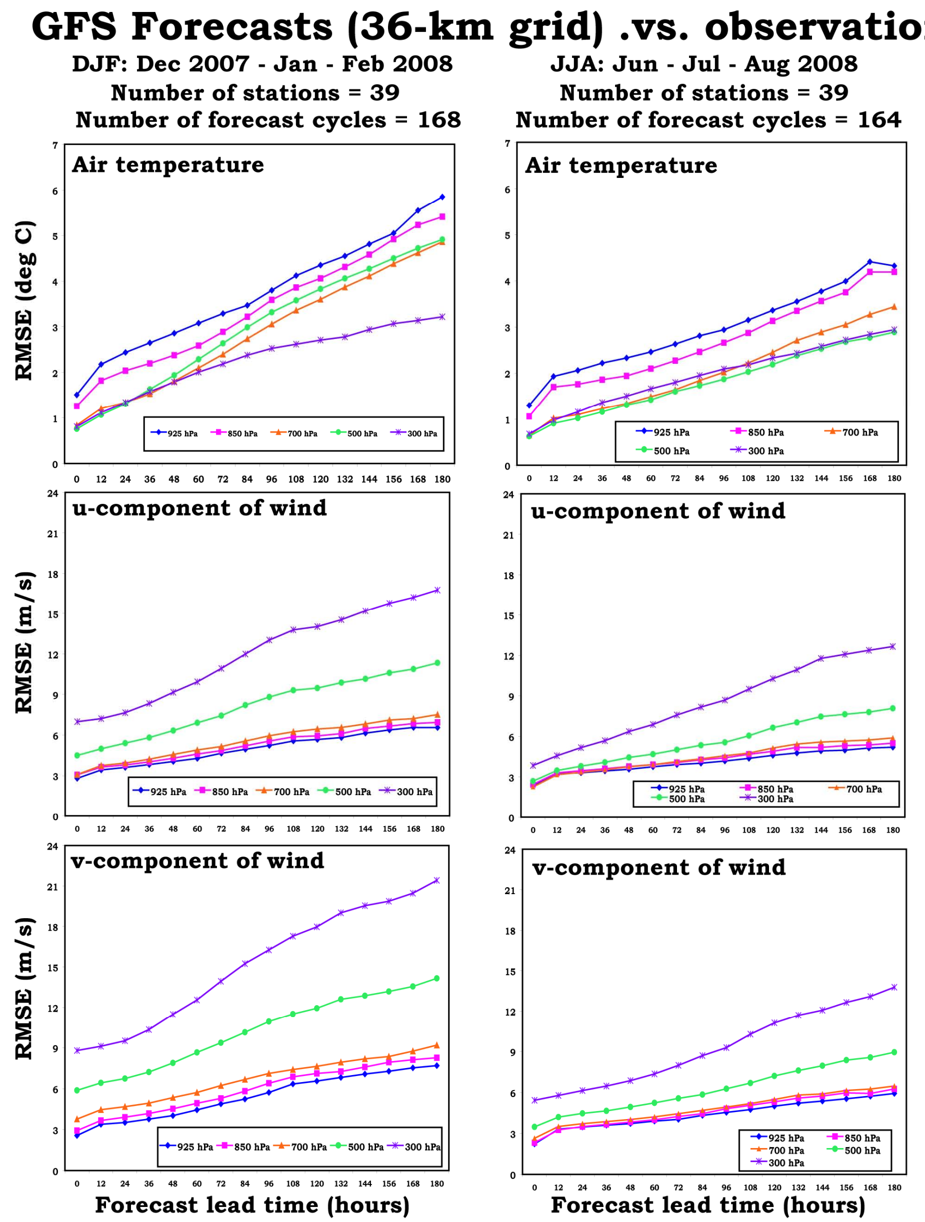


Fig. 4. The root-mean square error for the GFS forecasts using data from 39 radiosondes of the air temperature, zonal and meridional wind components as a function of lead time for winter months (left panels) and summer months (right panels) of 2007/2008. Colors represent different pressure levels.

One of the significant features is that the RMSE is generally higher for the winter than for the summer forecasts. One of the significant features is the relatively large RMSE in winter compared to summer. This is expected in light of the consequences of slight errors in the large-amplitude disturbances during the stormy season. The next question is how mesoscale models such as WRF and MM5 perform using the same radiosonde data as a baseline for one month in the winter and one in the summer (Fig. 5).

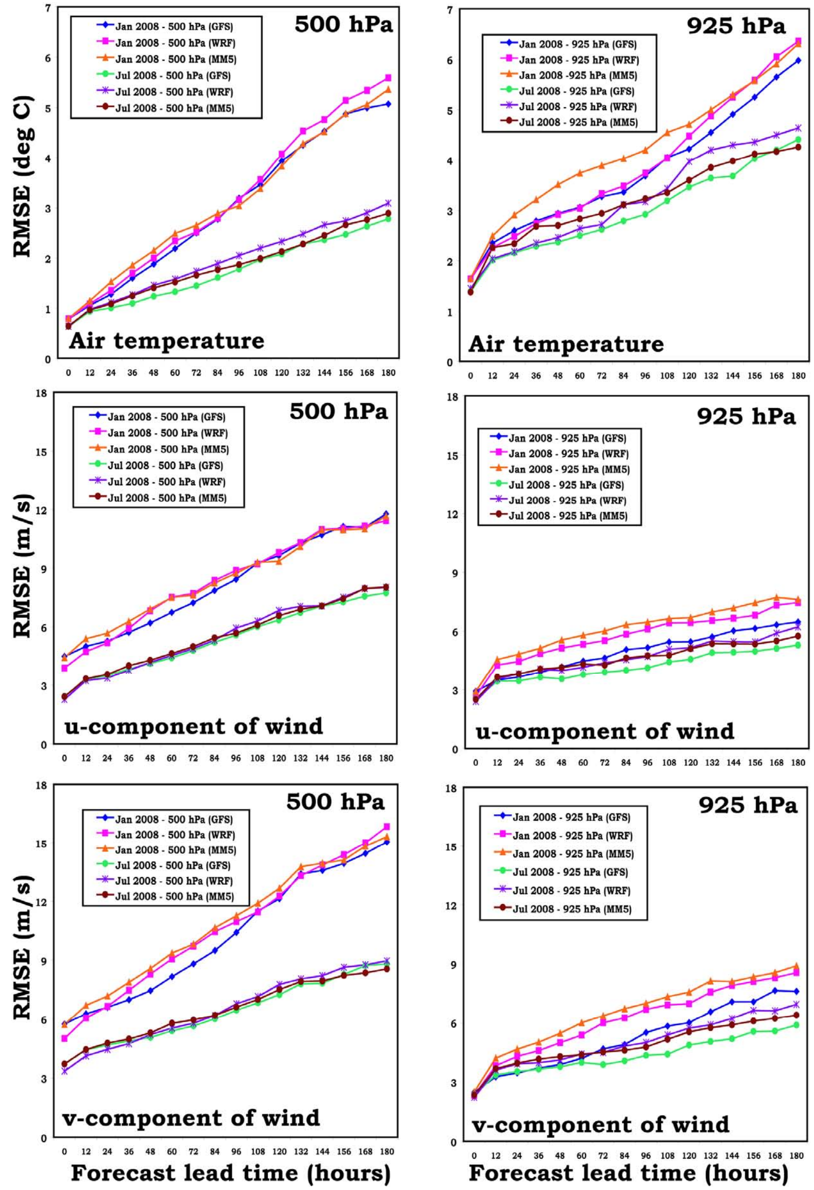


Fig. 5. The root-mean square error vs. lead time for the GFS, WRF, and MM5 forecasts using data from 39 radiosondes of air temperature, zonal and meridional wind components for a winter month (January 2008) and a summer month (July 2008). The results are shown for 500 hPa (left panels) and 925 hPa. Colors represent different models and associated months.

For the upper level (500 hPa), the differences between the winter and summer months are obvious for all models. Notice that there all models - global and mesoscale - show similar results. The differences between the seasons are dominant, while within a season there are no significant differences among the models. Consequently, according to this sample, even with the significant differences in the resolution between the global and mesoscale (1^o x 1^o vs. 36 km), there are no apparent advantages to mesoscale models in spite of more detailed physical parameterizations and better resolution. We would expect to see improved RMSE's for the mesoscale models incomparison to the GFS for the case when the observation stations capture the smaller-scale features of the weather systems. We will test this conjecture by using the surface network in contrast to the more-widely spaced upper-air network. This will be investigated further in the future.

IMPACT/APPLICATIONS

The results of this study will improve the predictability of high-resolution weather phenomena relevant to the Navy's operations, as currently applied to the Naval Air Station in Fallon, NV. However, the results and methodology of the multi-model ensemble mesoscale forecasting will significantly enhance the capability of accurate forecasts and nowcasts of winds, turbulence, cloud, fog, and visibility. This will aid in decision making and in the performance of low-level airborne and sea-based naval operations. The results may be applied to other areas of interest worldwide.

RELATED PROJECTS

Dr. Koracin is a P.I. on a project supported by another ARO grant that is focusing on visualization and virtual reality applications of the Fallon NAS high-resolution mesoscale forecasts. Dr. Koracin is a co-P.I. on an ARO Project entitled "Forecasting of Desert Terrain" where real-time experience and expertise is facilitating an interdisciplinary project linking dust emission modeling, atmospheric predictions and Lagrangian Random Particle Dispersion modeling. Dr. Koracin is also a co-P.I. on a recently completed multi-insitutional NSF-EPSCoR Project on Cognitive Information Processing: Modeling and Inversion where they are developing new methods of satellite data assimilation and investigation of predictability and chaos in numerical weather and climate forecasting (Vellore et al. 2007). He is also a lead investigator for a Climate Modeling component (global climate modeling and downscaling to regional, mesoscale, and microscale domains) of a recently awarded NSF-EPSCoR project focused on Climate Change. Dr. Lewis is collaborating with Dr. S. Lakshmivarahan, professor of computer science at University of Oklahoma, on a project that aims to identify the sources of bias error in numerical prediction. Information on the uncertainty in initial conditions, boundary conditions, and physical/empirical parameters will have bearing on the strategy for choosing members of the ensemble set.

REFERENCES

Beg Paklar, G., N. Zagar, M. Zagar, R. Vellore, D. Koracin, P.-M. Poulain, M. Orlic, I. Vilibic, and V. Dadic, 2008: Modeling the trajectories of satellite–tracked drifters in the Adriatic Sea during a summertime bora event. *J. Geophys. Res. (in press).*

Beg Paklar, G., D. Koracin, and C. Dorman, 2008: Wind-induced ocean circulation along California and Baja California coasts in June 1999. *Atmos. Res*. (submitted).

Dorman, C.E., and D. Koracin, 2008: Response of the summer marine layer flow to an extreme California coastal bend. *Mon. Wea. Rev.*, **136**, 2894-2922.

Isakov, V., A. Venkatram, J. Touma, D. Koracin, and T. L. Otte, 2007: Evaluating the use of outputs from comprehensive meteorological models in air quality applications: A case study in Wilmington, CA. *Atmos. Environ.*, **41**, 1689-1705.

Koracin, D., A. Panorska, V. Isakov, J. S. Touma, and J. Swall, 2007: A statistical approach for estimating uncertainty in dispersion modeling: an example of application in southwestern U.S. *Atmos. Environ.*, **41**, 617-628.

Lewis, J., 2005: Roots of ensemble forecasting. *Mon. Wea. Rev.*, **133**, 1865-1885.

McAlpine, J.D., D. Koracin, K. Veropoulos, D. Boyle, E. McDonald, and G. Lamorey, 2007: Determining atmospheric dust concentrations during strong flow perturbations using a digital-optical technique. *Lecture Notes in Computer Science: Advances in Visual Computing*, **4841**, 393-402.

Vellore, R., D. Koracin, and M. Wetzel, 2006: A method of improving cloud predictions for real-time weather forecasting and visualization. *Advances in Visual Computing*, *Lecture Notes in Computer Science 4292*, G. Bebis et al. (Eds.), Part II, Springer-Verlag, 544-553.

Vellore, R., D. Koracin, M. Wetzel, S. K. Chai, and Q. Wang, 2007: Challenges in mesoscale predictions of nocturnal stratocumulus-topped marine boundary layer and implications for operational forecasting. *Weather and Forecasting,* **22**, 1101-1122.

Weinroth, E., W. Stockwell, D. Koracin, J. Kahyaoğlu-Koračin, M. Luria, T. McCord, D. Podnar, and A. Gertler, 2008: A hybrid model for local and regional ozone forecasting. *Atmos. Environ.* (in press).